DEVELOPMENT OF NOVEL SOIL SALINITY SPECTRAL INDEX USING REMOTELY SENSED DATA: A CASE STUDY ON BALOD DISTRICT, CHHATTISGARH, INDIA

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ABSTRACT

Soil salinity is a known phenomenon worldwide. It has a substantial influence on crop productivity and environmental well-being. Conventional approaches to evaluate soil salinity are laborious and expensive, which need efficient approaches such as geospatial. Geospatial approaches have led to the development of several indices for soil salinity estimation. Existing soil salinity indices are region specific and not verified for different regions. This study was conducted in the Balod district of Chhattisgarh, India. Landsat 9 imagery along with field electrical conductivity (EC) were used to evaluate the existing soil index and develop a new soil salinity index. A Soil multi-parameter recorder was used to collect 69 EC samples for April and May 2024. Sixteen spectral indices were evaluated to verify the applicability in the study area. The results showed that the existing spectral indices had a weak correlation with field EC values. Therefore, we have developed the new index by combining the Near Infrared surface reflectance, redsurface reflectance, and Shortwave Infrared-1 surface reflectance bands and using a linear regression analysis.The soil salinity classification was used to categorize the new index. The results showed that 78.40 % of the region is slightly saline, 16.50 % is moderately saline and 1.46 % is strongly saline. This study demonstrates a strong correlation between reflectance values and field EC data with an R^2 value of 0.83 and a mean relative error of 10 %. This study provides a reliable geospatial approach for soil salinity evaluation and sustainable land management techniques to improve agricultural productivity in semi-arid, arid regions with varying soil properties and salinity levels.

Keywords: Electrical Conductivity, Geospatial, Remote Sensing, Soil Salinity, Spectral soil salinity Index

INTRODUCTION

Soil salinity accumulates due to various processes, such as evapotranspiration (ET) by plants, which increases salt concentration through the root zone and accumulates salts below it (Corwin & Scudiero, 2019). Soil salinity is a significant global challenge, particularly prevalent in arid and semi-arid areas including India. This phenomenon impacts approximately one-third of the world's inundated agricultural area (Singh *et al*., 2017). On a global scale, degraded soil affects one billion hectares of land in many nations, such as China, India, Pakistan, Iran, Australia, and the United States (Mohammadifar *et al*., 2022). As a result, salinization can reduce crop yield up to 50 %, saline soil economically results in low agricultural productivity that ranges from 12.7 to 27.3 billion dollars annually worldwide. Demand for food has been increasing many times considering the rate of population in a country like India. In a recent study, it was projected that the existing 311 million tons of food grains may rise to 350 million tons by 2050 (Kumar & Sharma, 2020). Human activity, including urbanization and inadequate irrigation techniques, causes annual increases in soil salinity in India.The spatial distribution of salt-affected soils in the area is highly sensitive and assessed by various characteristics including parent material, penetrability, water table depth, quality of groundwater, topography, irrigation practices, rainfall, drainage, and humidity (Somvanshi *et al*., 2020). To achieve food security in India, the government prioritized to expanding agriculture and increasing crop productivity. As a result, the government of India initiated to restore 26 million hectares of degraded lands by 2030 and plans to further restore 50 % salt-affected agricultural land till 2050.

The central and state governments of India are responsible for planning and management of soil for sustainable growth of agricultural lands. Individual state policies exist in India, which are also accountable for planning and management of soil health. Many states in India such as Gujarat, Maharashtra, Rajasthan, and other states are salt affected (Mandal, 2022). Some states like Karnataka and Madhya Pradesh including Chhattisgarh have low to moderate salinity. Considering the increasing demand for food and changing climatic conditions, there is a need for detail investigations in such states. To address this issue, we selected the Balod district in Chhattisgarh as study site. To sum up, the increasing levels of saline soil have significant ramifications for the environment, agriculture, and related ecosystems. It has a detrimental effect on the growth of plants, their capacity to assimilate nutrients, and the overall productivity of agricultural endeavors (Rani *et al*., 2022).

Traditionally, the soil salinity has been estimated using field and laboratory-based methods such as field based Electrical Conductivity (EC), laboratory based apparent electrical conductivity, chemical analysis of soil sample, soil water extract etc. (Gojiya *et al*., 2023). For instance, first soil sample from a field can be collected and transported to the respective laboratory. Second, soil sample has been analysed as per the standard protocols as described by several agencies. In case of Indian agency, Bureau of Indian standard (BIS: 14767:2000) has been used to measure soil salinity for several decades. Similarly, other countries have also well documented approaches such as saturated soil paste extract, different soil water ratios such as 1:5, 1:2.5 (IS 14767: 2000, 2000). Thirdly, standard soil water extract has been prepared using distilled water and collected soil sample for different combinations of water and soil ratios. Finally, the salinity has been measured for each prepared samples using conductivity meter at 25 degrees Celsius. The standard unit of measurement for EC is deci-Siemens per meter (dS/m). Based on the obtained EC values, the standard classification of soil salinity ranges from non-saline to excessively high saline. Soil salinity, measured by the conventional approach as discussed above, indicates a quantitative assessment of the amount of salt present in the soil. It is often determined by measuring the conductivity of a soil-water solution or using a soil probe. Despite the simplicity and wide acceptance of conventional methods, these approaches require physical labour, time consuming and uneconomical, and these approaches are inadequate for larger geographical area. However, geospatial approaches with ground truthing have been established as efficient and reliable technique for mapping soil salinity at high spatial-temporal scales, particularly at the regional scale and inter annual variations, as high-resolution satellite data are readily available (Mandal *et al*., 2023; Corwin & Scudiero, 2019).

Over the past three decades, the enhanced availability of remotely sensed data, characterized by improved spatial and spectral resolutions as well as temporal and multi-scale analyses, has fostered greater impetus to establish a coherent relationship among various associated surface elements, including soil and land use/land cover (Ankana, 2016). As the rapid evolution of remotely sensed technology in several field of science, this technology has also been widely used in various areas of the agricultural sector. This includes applications such as evaluating basin characteristics, assessing soil moisture content, analysing soil salinity levels, predicting drought events (Sahab *et al*., 2021; Gojiya *et al*., 2023). For example, multiple studies have emphasized the importance of employing remote sensing methods to accurately map soil salinity. Studies have demonstrated that the integration of different satellite images with ground-sampling data can enhance the precision of salinity monitoring (Chen *et al*., 2024; Gad *et al*., 2022; Hihi *et al*., 2019). Researchers in Egypt and China have used Landsat images and machine learning algorithms to create accurate maps of soil salinity, demonstrating the effectiveness of remote sensing in identifying soil salinity, crucial for agricultural and environmental management (Gad *et al*., 2022). Remote sensing technologies have emerged as valuable tools for accurately detecting, monitoring, and mapping salt-affected soils, providing crucial data for decision-making and remediation efforts in agriculture. An efficient approach in dry and semi-arid areas to identify soil salinity is spectral indices (Fathizad *et al*., 2020). The specific environmental factors affect the choice of spectral indices. This work evaluates the comparison for further selection and chooses the often-used soil salinity indicators to generate a strong grouping in the soil salinity model (Wang *et al*., 2020). Therefore, geospatial technologies have emerged as less labor intensive, efficient, and economical means of obtaining both qualitative and quantitative spatial information on saline soils (Ghasempour *et al*., 2024; Salem & Jia, 2024; Zhang *et al*., 2024). In addition, geospatial based approaches provide an estimation of soil salinity indices for different time periods considering varied cropping seasons.

Among several geospatial approaches, spectral based indices have been widely used by previous researchers. The basic principle lies in developing such indices based on integrating multiple bands in a single index (Shahrayini & Noroozi, 2021; Scudiero *et al*., 2014). Several spectral indices have developed in previous decades to identify regions affected by soil salinity. For instance, Huete (1988) has developed a soil adjusted vegetation index (SAVI) which was specifically developed using transformation technique to reduce the impact of soil brightness on spectral vegetation indices that utilise red and near-infrared (NIR) wavelengths. Scudiero *et al*., (2014) developed canopy response salinity index (CRSI) to monitor plant suitability using all the visible and near-infrared bands of the Landsat 7 satellite sensor. The CRSI index highlights the small reflectance peak at 400-500 nm wavelengths (blue and green bands) and the sudden change in reflectance between red and near-infrared wavelengths. Khan *et al*., (2007) have also demonstrated a comprehensive methodology that merges ground truth data with satellite images to accurately map and monitor soil salinity. This technique offers distinct benefits compared to traditional methods. Douaoui *et al*., (2006) examines several mapping techniques, such as ordinary kriging and regression-kriging, and concludes that regression-kriging is the most effective way for enhancing salinity estimations. Using this approach salinity index 3 & 4 were developed. This index highlights the need of integrating remotely sensed data with ground-based monitoring networks to enhance the accuracy of soil salinity monitoring in semi-arid to arid climatic conditions. Similarly, other indices such as salinity index 1, salinity index 2 and BI index were developed (Khan *et al*., 2001). However, these approaches only offer limited information about soil salinity in specific geographic locations.

Based on the previous literatures and aforementioned methods, several spectral indices have been developed for estimating soil salinity which is based on the integration of multiple bands. However, most of the soil salinity indices were confined to a particular study site with limited soil type and certain agro-climatic zones. Further, it has not been validated for different region with complex agro-climatic zones and soil properties. Therefore, the present study proses to develop a region-specific index based on remotely sensed data and field observation. Also, it has been observed that the spectral soil salinity indices don’t have better correlation with field observation data of electrical conductivity. In addition, it has been also reviewed that no soil salinity estimation or investigation has been done in the Chhattisgarh region using geospatial approaches. As per the reports published by state and central government of India, it has been observed that the Balod district in Chhattisgarh is at a verge of soil salinization due to poor water and land management.

Based on the mentioned research gaps, the aim of the present study is to develop new soil salinity index using remote sensing and ground truth measurements from field. The objectives of study are 1) To develop and evaluate different spectral indices for soil salinity assessment and monitoring and 2) To develop the effective spectral indices for the proposed study region of the Balod district in state of Chhattisgarh, India.

METHODS

Study area

The current research is conducted in the Balod district of Chhattisgarh, which is a paddy dominated region and located along the banks of the Tandula River in the central part of the state. The district covers an area of 3527 km^2, ranging from latitude 20°36' to 21°2' N, and longitude 81°1' to 81°29' E (Fig. 1). The district experiences high temperature over the period of March to mid-June. The district has semi-arid to arid climatic conditions where the average temperature in summer season ranges from 35°C to 40°C. May/June is the warmest months compared to all other months, and the average annual precipitation in the Balod district is 1089 mm approximately (https://balod.gov.in/en/about-district/geography-climate/). Most of the precipitation of the Balod district falls between June to September. In recent decades, the Balod district area has seen significant development both in agriculture and industrial sector. The Balod district, encompassing around 2,166 km^2 is predominantly agricultural, with 620 km^{2}of vegetated and built-up areas, and 79 km^2 of water bodies, highlighting significant agricultural activities (Fig. 2).

We have selected the Balod district as a study site for two reasons: (1) There has been a significant development of agricultural sector which leads to more application of fertilizers and overuse of ground water. (2) Low to moderate salinity has been observed in the Balod district (https://nbsslup.icar.gov.in/).

Fig. 3 shows an overall process showing the steps involved for the development of new soil salinity index. The method section has been divided into (1) Estimation of soil salinity using existing approaches. (2) Development of new soil salinity index for the study area.

Fig. 1: Location map of the Study area, Balod District, Chhattisgarh

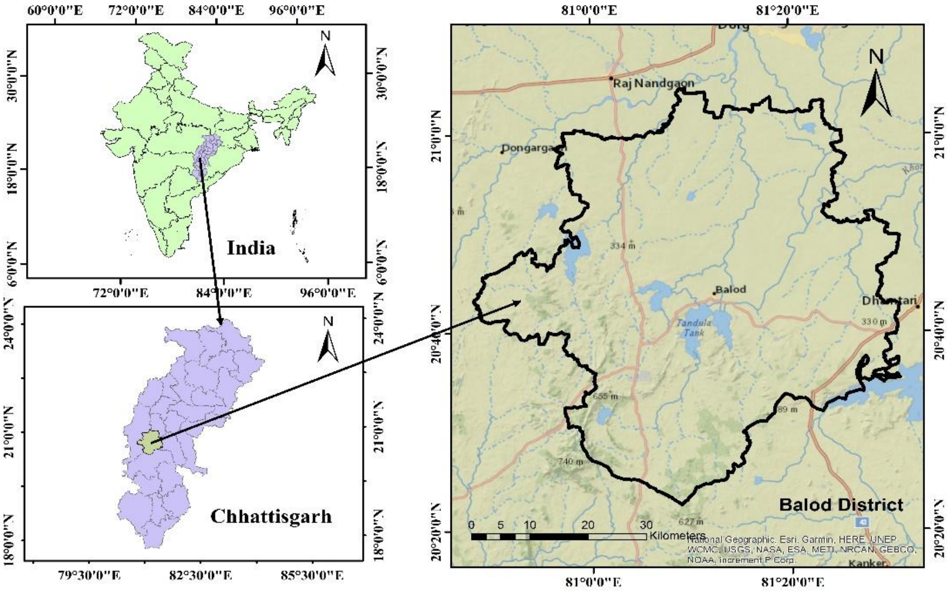


Fig. 2: Land use Landcover of the Balod District

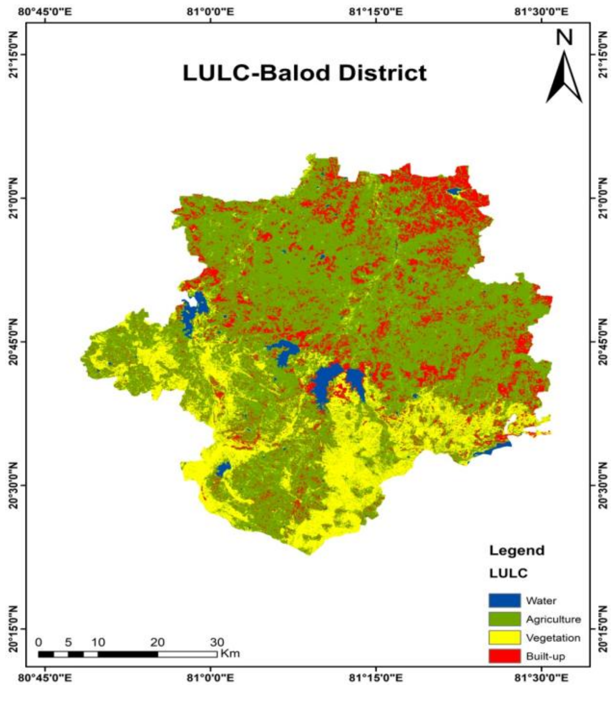
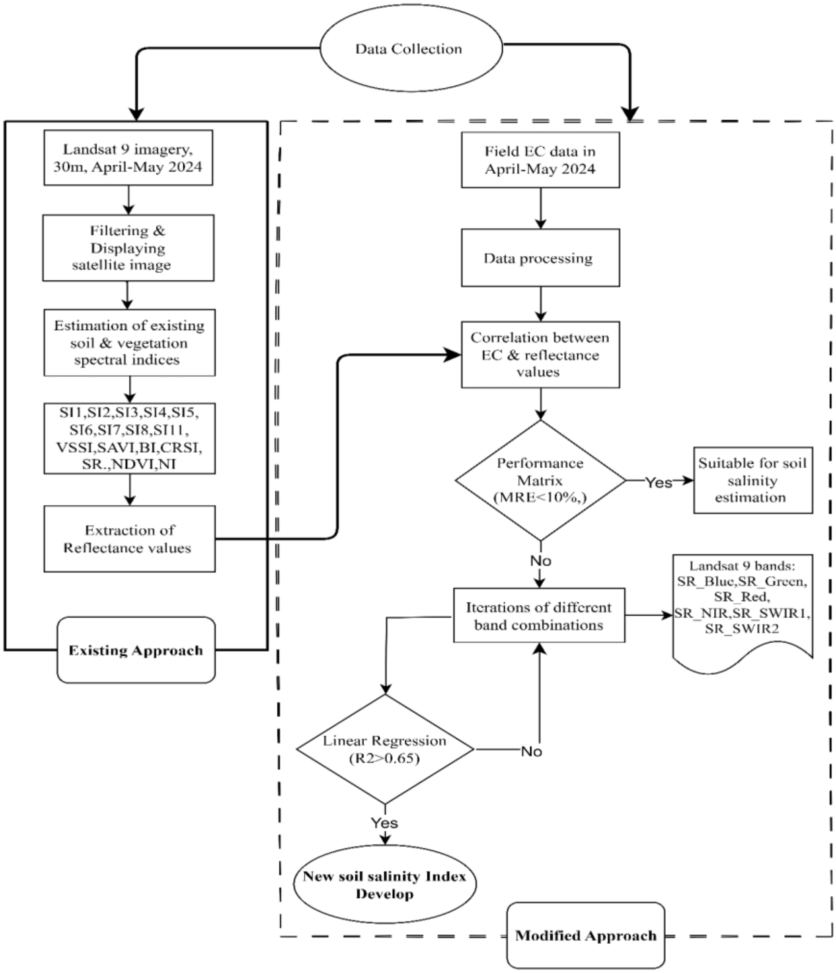


Fig. 3: Methodology flow chart



Estimation of soil salinity using existing indices

We have collected two different sets of data: (1) remotely sensed data and (2) in situ EC data. Remotely sensed data include USGS Landsat 9 Level 2, Collection 2, Tier 1 for the entire study site. This dataset contains atmospherically corrected surface reflectance and land surface temperature derived from the data produced by the Landsat 9 OLI/TIRS sensors. These images contain 5 visible and near-infrared (VNIR) bands and 2 short-wave infrared (SWIR) bands (Landsat-9 image courtesy of the U.S. Geological Survey). These imageries have been downloaded and further processed using Google Earth Engine (GEE), a cloud-based geospatial analysis platform. The processing of imageries involves cloud filtering, histogram equalization, and image enhancement. Landsat 9 satellite imagery contains surface reflectance bands such as SR_B1, SR_B2, SR_B3, SR_B4, SR_B5, SR_B7 etc. Here SR stands for surface reflectance. In the case of in situ electrical conductivity (EC) data, a total of 69 EC samples were collected during April-May 2024 from the agricultural land of the study area using soil multiparameter recorder (Fig. 4). The soil multiparameter recorder is a device used to measure field EC values. The EC data was initially recorded in micro siemens/ centimetre unit and later converted into deci-siemens per meter. The duration of Landsat imageries and field observations were same.

Development of existing spectral soil salinity indices

Numerous methods were available to estimate the soil salinity indices using remotely sensed data, including Landsat. Based on the recent literature and commonly used approaches, we have selected 16 different spectral indices (Table 1). These methods are based on several band combinations, which include blue, red, green, nir, swir1, swir2 and others. These indices were derived through several field and laboratory trials. Empirical equations were used for different band combinations. To estimate the soil salinity of study area using existing approaches, we have used field and Landsat datasets. We utilized several formula and band combinations as described in Table 1. The soil salinity was estimated for each of the selected methods. Furthermore, we compared estimated soil salinity with the field data. In order to validate the results, coefficient of determination (R^2) and mean relative error (%) were determined. We observed a low correlation between the existing approaches and field data.

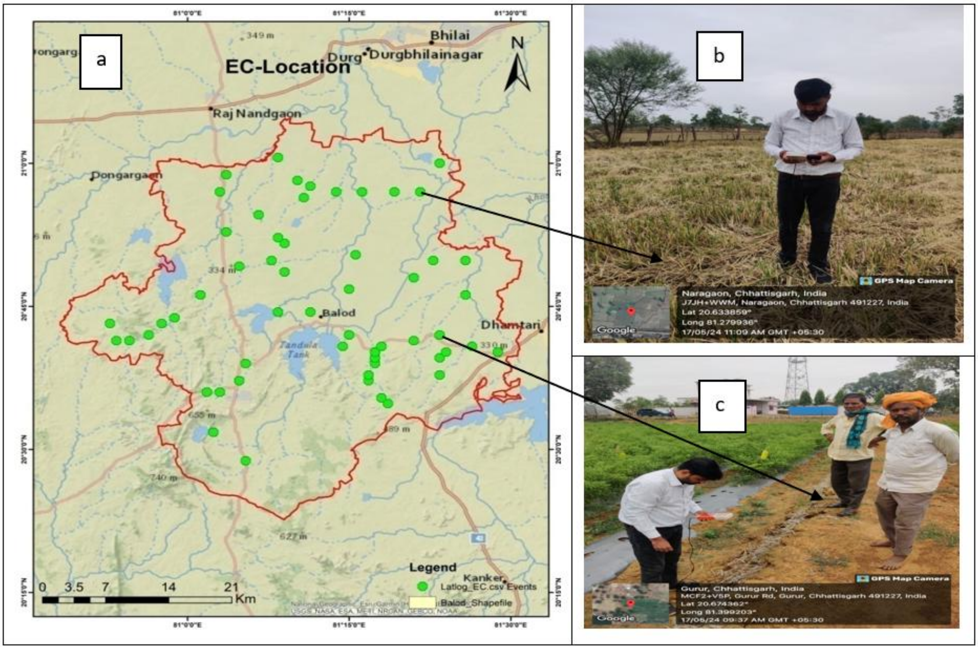
Table 1: Existing soil salinity and vegetation spectral indices

Spectral Indices	Expressions	References
Salinity Index 1(SI1)	√((blue*red))	(N. M. Khan et al., 2001)
Salinity Index 2 (SI2)	(blue− red) / (blue + red)	(N. M. Khan et al., 2001)
Salinity Index 3 (SI3)	green*green + red*red + nir*nir	(Douaoui et al., 2006)
Salinity Index 4 (SI4)	√((green*green) +(red*red))	(Douaoui et al., 2006)
Salinity Index 5 (SI5)	(blue/bed)	(S., A. A. Khan, 2007)
Salinity Index 6 (SI6)	(blue-red)/ (blue + red)	(S., A. A. Khan, 2007)
Salinity Index 7 (SI7)	(green*red)/blue	(S., A. A. Khan, 2007)
Salinity Index 8 (SI8)	(nir-red)/green	(A. Abbas et al. 2007)
SAVI	1.5*(nir-red)/(nir+red+0.5)	(A.R_Huete, 1988)
VSSI	2*blue-5*(green + red)	(Dehni, A., Lounis, M., 2012)
NDSI	(red-nir) / (red + nir)	(N. M. Khan et al., 2001)
SR	(green-red)/ (blue + red)	(FAO, 2020)
CRSI	((nir*red)-(green*blue))/ ((nir*green) + (green*blue)) * 0.5	(Scudiero et al., 2014)
Salinity Index11 (SI11)	(swir1) / (swir2)	(FAO, 2020)
BI	√(((red*red) + (nir*nir)))	(N. M. Khan et al., 2001)
NDVI	((nir-red)/ (nir+ red))	(FAO, 2020)

Development of new soil salinity index

In this research, it has been observed that the existing soil salinity and vegetation spectral indices were not suitable for the study region due to poor correlation with the field EC data. To obtain accurate and high correlation with the field EC data, the new soil salinity index was developed. To develop a new soil salinity index of the study area, we used different combination of Landsat 9 imagery bands, field observations and statistical techniques. The different combination of bands includes SR_B2, SR_B3, SR_B4, SR_B5, SR_B6 and SR_B7. Several iterations were performed to obtained better correlation between field EC values and satellite derived reflectance values. Linear regression was employed to establish the empirical relationship between satellite derived reflectance values and field EC values. To obtain the better correlation, we fixed a threshold range of R^2 greater than 0.65 and mean relative error below or equal to 10 %.

Fig. 4: Field measurement of Electrical conductivity: (a) Location map of 69 sample (b and c) sample field photographs at Naragaon and Gurur



RESULTS AND DISCUSSION

Existing soil salinity indices

Total 16 spectral indices such as SI1, SI2, SI3, SI4, SI5, SI6, SI7, SI8, VSSI, SAVI, SR, NDSI, CRSI, NDVI, BI, SI11 were generated using Landsat 9 bands which includes blue, red, green, nir, swir1 and swir2 on Google Earth Engine platform (Table 1) and these indices were further reclassified. These indices were categorized as per soil salinity classification given in Table 2. The Table 2 shows the classes of soil salinity as Non saline, slightly saline, moderately saline, strongly saline, very high salinity and excessively high salinity The reclassified maps have six classes such as non-saline, slightly saline, moderately saline, strongly saline, very high saline, and excessively high saline.

Table 2: Soil salinity classification (Abuelgasim & Ammad, 2019)

S. No	Soil salinity class	EC values (ds/m)	Description
1	Non saline	0 – 0.15	Very low: plants may be starved
2	Slightly saline	0.16 – 0.50	Low: if soil lacks organic matter; satisfactory if soil is high in organic matter
3	Moderately saline	0.51 – 1.25	Medium: satisfactory range for established plants
4	Strongly saline	1.26 – 1.75	High: Okay for most established plants. Too high for seedlings or cuttings
5	Very high saline	1.76 - 2	Very high: plants usually stunted or chlorotic
6	Excessively high saline	>2	Excessively high: plants severely dwarfed, seedlings and rooted cuttings frequently killed.

The CRSI, NDSI and BI show non-saline while NDVI shows slightly saline in most of the region of the study area (Fig. 5). Similarly, SI1 and SI2 show non-saline whereas SI11 shows moderately saline, and SAVI shows slightly saline (Fig. 6). Fig.7 represents other salinity indices such as SI6, SI5, SI4 and SI3. Among these indices, SI6 shows no evidence of salinity in the study area while SI3 indicates slightly saline for a very small area. Also, SI 5 yields no salinity, slight salinity for most of the region and moderately saline for the rest of the region in the study area. VSSI, SR and SI7 have shown a similar trend of soil salinity in the study region as most of the area comes under non saline class. Conversely, SI8 has shown large part of study site covers moderately saline class (Fig. 8). The reflectance values of each existing spectral indices corresponding to the field EC sample were extracted in order to establish a correlation between the field EC data and reflectance values.

Fig. 5: Spectral Soil salinity index maps of NDVI, NDSI, CRSI and BI

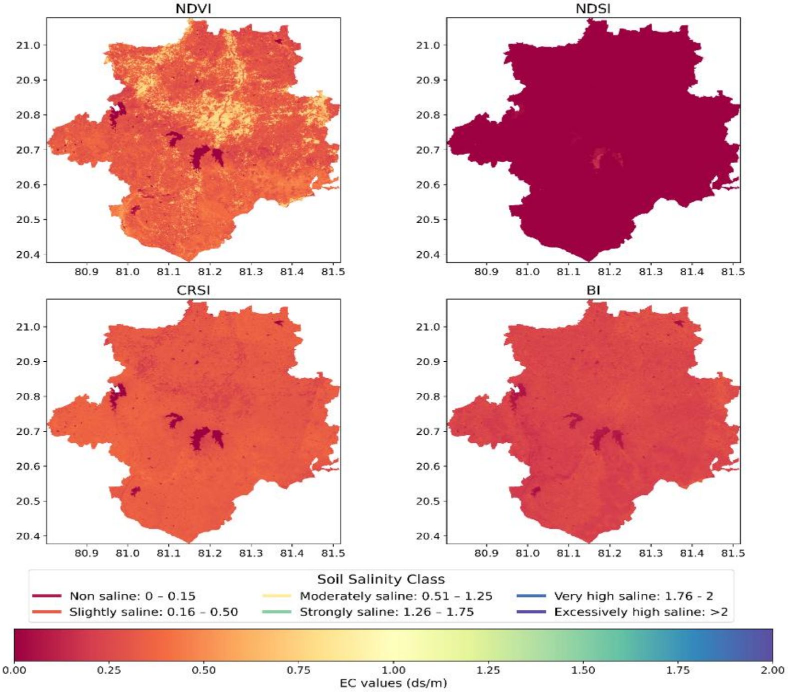


Fig. 6: Spectral Soil salinity index maps of SI11, SI1, SAVI and SI2

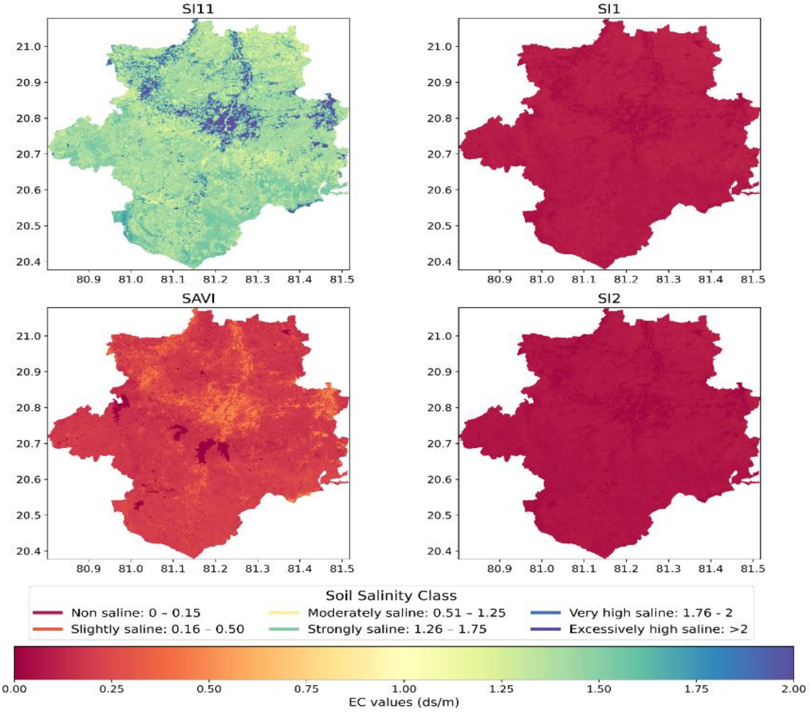


Fig. 7: Spectral Soil salinity index maps of SI6, SI5, SI4 and SI3

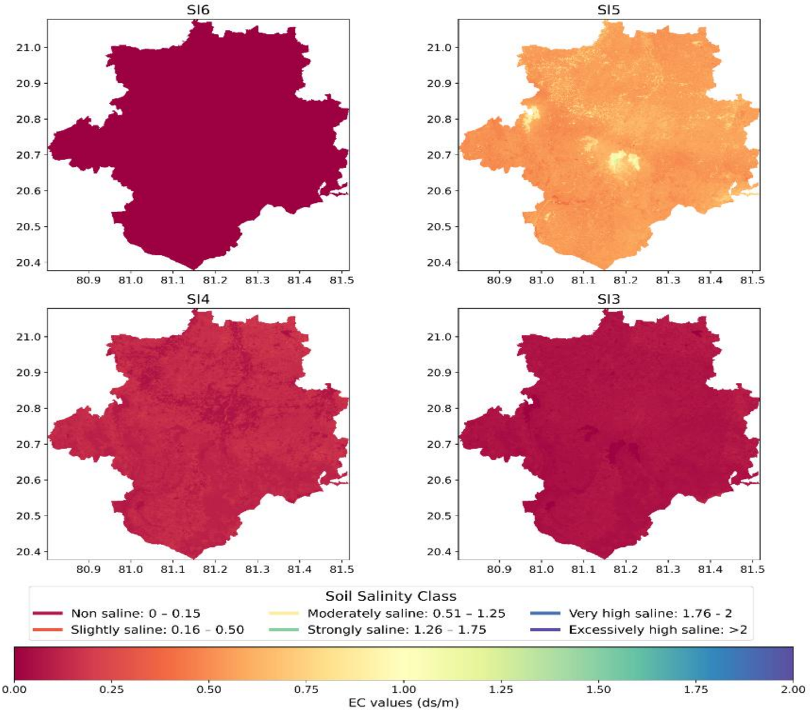
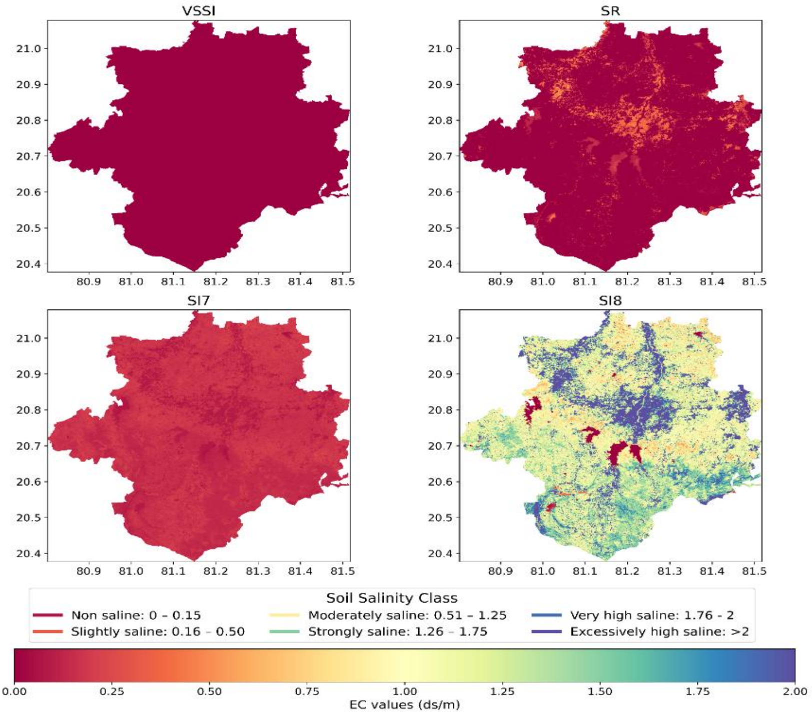


Fig. 8: Spectral Soil salinity index maps of VSSI, SR, SI7 and SI8



To see the performance of existing approaches, we have used three statistical measures, which include the coefficient of determination (R^2), mean relative error, and Pearson correlation. The CRSI, NDSI, SI1, SI2, SI3, SI4, and SI7 spectral indices have shown the negative correlation, whereas SI5, SI6, SI8, VSSI, SAVI, SR, NDVI, SI11 have shown positive correlation with field EC data. The highest R^2 value of 0.68 was observed with the ‘SR’ followed by ‘SI11 index’ with R^2 value of 0.65 and other spectral indices in decreasing order of R^2 value. Similarly, Pearson correlation shows higher to lower values as also observed for R^2. The highest range of mean relative error were found for most spectral indices that include VSSI, SI11, SI6, NDSI, SI5, SI8, SI3, SI7, CRSI, SI1, SI2, SI4, and SAVI. However, the mean relative error was lowest in ‘NDVI’ which was 19 % followed by ‘SI5’ which was 31 % as shown in Table 3.

It has been observed that each of the existing approaches produced distinct results. It indicates that these methods have been developed for specific regions with varied agro-climatic conditions, and soil characteristics. The results suggest that the developed spectral indices have poor correlation with the field EC data. So, these results indicate that the existing spectral indices have a poor correlation with the electrical conductivity values. Therefore, to improve the correlation and minimize the errors, a new soil salinity index was developed using different band combinations.

Table 3: Performance matrix of existing indices

S. No	Spectral Indices	R-squared	Pearson Correlation Coefficient	Mean relative error
1	BI	0.01	0.07	0.49
2	CRSI	0.38	-0.62	0.34
3	NDSI	0.63	-0.8	1.86
4	NDVI	0.63	0.8	0.19
5	NI	0.01	-0.1	10.46
6	New	0.83	0.91	0.1
7	SAVI	0.55	0.74	0.5
8	SI1	0.55	-0.74	0.81
9	SI11	0.65	0.81	2.07
10	SI2	0.56	-0.75	0.85
11	SI3	0	-0.03	0.86
12	SI4	0.53	-0.73	0.73
13	SI5	0.32	0.56	0.31
14	SI6	0.13	0.36	4.49
15	SI7	0.45	-0.67	0.66
16	SI8	0.6	0.78	2.23
17	SR	0.68	0.83	1.06
18	VSSI	0.53	0.73	2.7

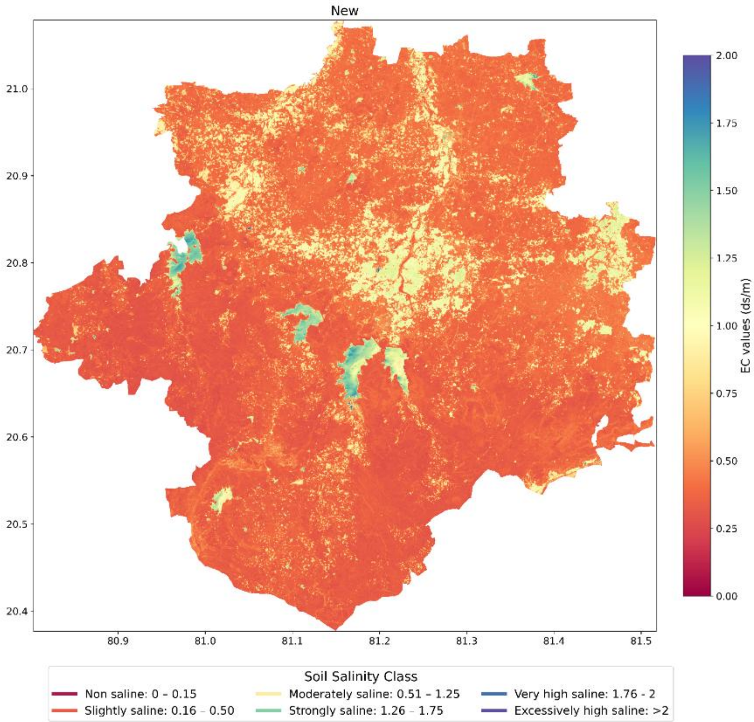
Newly developed soil salinity spectral index

In the previous section, it has been observed that the reflectance values from the existing spectral indices have a poor correlation with the field EC values. The coefficient of determination (R^2) came in less than 0.65, therefore a linear regression technique was applied with multiple iterations of different band combination still R^2 became greater than 0.65. SR_B2 to SR_B7 bands of Landsat 9 were used for different combinations. After multiple trials, a new soil salinity index was developed (Eq.1).

0.48*(SR_B5+SR_B4)/SR_B6-0.18 Eq. 1

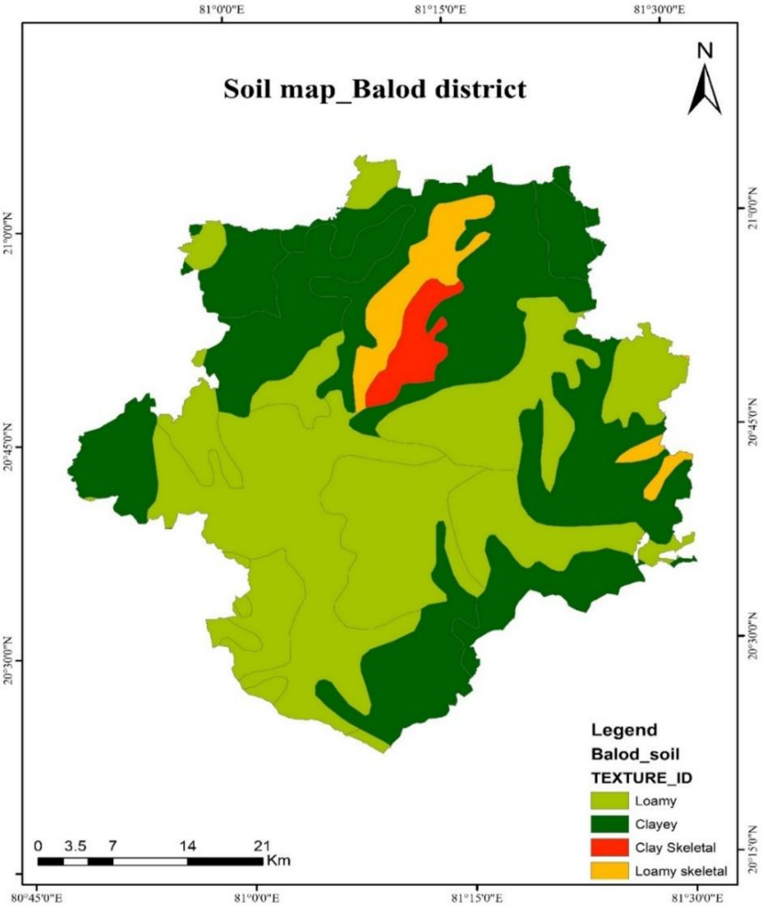
In equation 1, SR_B4 stands for red band surface reflectance, SR_B5 indicates near infrared bands surface reflectance and SR_B6 indicates short wave infrared 1 surface reflectance. The newly developed soil salinity index (Fig. 9) was further classified according to the classification given by (Abuelgasim & Ammad, 2019).

Fig. 9: New soil salinity spectral index map



The result indicates that 78.40 % of area of Balod district was under slightly saline class whereas 16.50 % of the area classified as moderately saline class while 1.46 % of the area comes under strongly saline class. The study area predominantly features clayey and loamy textured soil (Fig. 10). These soils have poor drainage and high to moderate water retention properties which leads to make them salt prone. Therefore, the large area of the study region comes under slightly saline zone. The moderately saline class covers 16.95 % area where clayey soil properties are found.

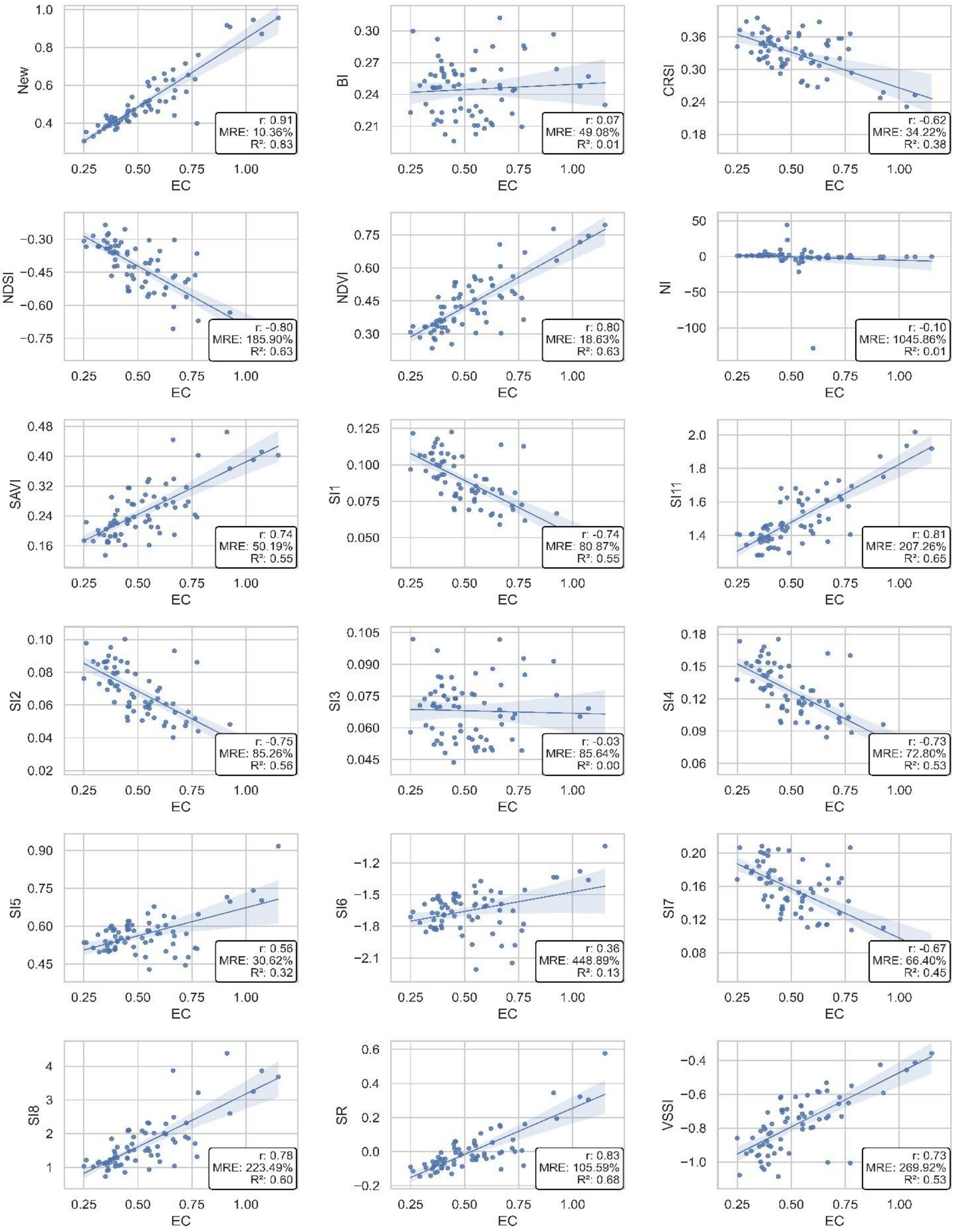
Fig. 10: Soil map of Balod District



The new soil salinity index was validated with the field electrical conductivity collected from the study area with reflectance values of spectral indices. The reflectance values were extracted from new soil salinity index from the same location where electrical conductivity was collected. It has been observed that the reflectance values shown highest R^2values of 0.83 and mean relative error of 10% with the field EC data. This result indicates a strong, positive and accurate relationship between satellite derived reflectance values and field EC data. (Fig. 11)

Variable of importance (VIMP) was also derived using random forest model. To ensure accurate soil salinity prediction, variable of importance helps to determine relatively better spectral indices in a predictive model. To estimate the relatively better spectral indices using variable of importance, 17 variables were used, such as SI1, SI2, SI3, SI4, SI5, SI6, SI7, BI, SI8, VSSI, SAVI, SR, NDSI, CRSI, NDVI, SI11, and New. The variable of importance of each spectral indices was evaluated considering random forest model. The top 5 variables of the random forest model were New, SI2, SI8, SAVI and SI11 and their score was 0.57, 0.06, 0.04, 0.033 and 0.03 respectively. Out of all the spectral indices, new index was found as a most important variable for predicting soil salinity (Table 4). However, it has been observed that the VIMP score is very low from the NI onward. The reason for the low values of VIMP score was due to the relative importance of the performance matrix.

Fig. 11: Performance matrix of existing spectral soil salinity indices



For the development of the new soil salinity index, the near-infrared (SR_NIR) and shortwave infrared I (SR_SWIR I) bands of Landsat 9 were selected as these were found to be better for mapping and monitoring of soil salinity in arid and semi-arid regions (Zhang *et al*.,2022 ; Li *et al*.,2021).The efficacy of these bands in assessing soil salinity during various studies that compare Landsat 8with Sentinel-MSI sensors is indicated by the excellent linear connections between reflectance values in these bands (Mandal, 2022).The spectral characteristics and interaction with salinized soils help SWIR1 and NIR bands to be more sensitive to soil salt (Bandak *et al*., 2024).Strong association between SWIR1, NIR bands and salt concentration in soil helps them to clearly indicate the extent of soil salinity. The Fig. 12 shows the spectral reflectance curve across different Landsat 9 bands for the study area. The average reflectance values were used to estimate spectral reflectance curve for each band, such as SR_B2, SR_B3, SR_B4, SR_B5, SR_B6, and SR_B7. The x-axis indicates the Landsat 9 surface reflectance bands, and the y-axis indicates the average reflectance. The average reflectance curve shows flat from SR_B2 to SR_B4 whereas a gradual rise in average reflectance is observed for SR_B5 and SR_B6 while the average reflectance value for SR_B7 is nearly same as SR_B2.

Based on the soil characteristics and agro-climatic conditions and aforementioned literature, the Near infrared (SR_NIR), red and short-wave infrared1 (SR_SWIR 1) was found to be more adequate. The performance matrix of newly developed soil salinity index shows the validity of this region-specific index based on remotely sensed data and field observation.

Fig. 12: Surface reflectance curve

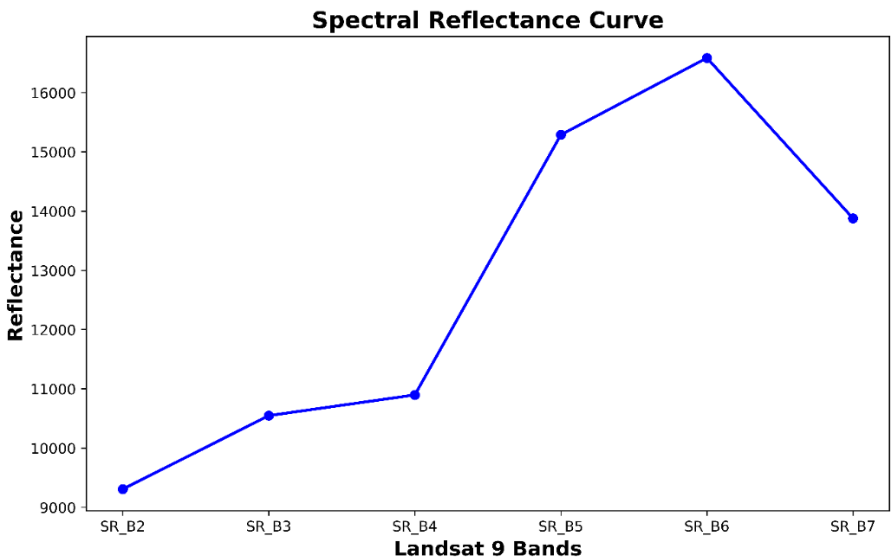


Table 4: Variable of importance

S.No	Spectral Indices	VIMP score
1	New	0.57
2	SI2	0.062
3	SI8	0.043
4	SAVI	0.033
5	SI11	0.033
6	SI7	0.030
7	NI	0.026
8	CRSI	0.025
9	SI3	0.024
10	SR	0.024
11	SI6	0.023
12	SI5	0.019
13	NDSI	0.018
14	SI4	0.018
15	NDVI	0.017
16	VSSI	0.015
17	SI1	0.004

CONCLUSION

This research was conducted in the Balod district of Chhattisgarh, India. The study emphasizes the effectiveness of remote sensing technologies, specifically the integration of Landsat 9 satellite imagery, in precisely monitoring and assessing soil salinity. The traditional methods employed to assess soil salinity need a substantial expenditure of human effort and financial resources. Hence, it is crucial to develop remote sensing technologies that are both efficient and economical. In this study, 69 samples of electrical conductivity (EC) were collected using a soil multiparameter recorder from the study area. The objectives of the study were to evaluate existing spectral indices for soil salinity assessment and to develop the region-specific spectral indices for the proposed study area in the semi-arid and arid climate. Existing soil and vegetation soil salinity indices were developed, and their performance matrix was evaluated with the field EC data. Overall, a poor correlation was observed between exiting spectral indices and field EC values. A new soil salinity index was developed by integrating the near Infrared, red and shortwave Infrared 1 bands, in order to address the limitations of existing indices. The new soil salinity index had a significantly stronger correlation with EC data, as evidenced by a high R^2 value of 0.83 and a mean relative error of 10 %. The updated soil salinity index reveals that 2920.29 sq.km area of the Balod district exhibits a slight salinity, whereas 614.68 sq.km area under a moderate salinity level and 54.52 sq.km area covers a strong level of salinity. The results highlight the substantial improvements in correlation and accuracy achieved by the new index compared to the existing spectral indices.

In summary, the development of the new soil salinity index in this study was found to be very useful for assessing soil salinity in a region of varying agro-climatic conditions and soil properties. The geospatial approach provides an accurate and efficient way to evaluate soil salinity. It is crucial to promote sustainable land management and enhance agricultural productivity in regions affected by higher soil salinity. This study not only improves the scientific understanding of soil salinity assessment but also offers practical solutions for agricultural stakeholders and policymakers who want to reduce the harmful effects of soil salinity on crop yield and environmental health. Integrating remote sensing technology with ground-truth data is a promising approach for economically monitoring soil on a large scale. This technique serves as a paradigm for future research and applications in the similar agricultural region.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

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